



Present status and overview of potential of renewable energy in Cote d'Ivoire



Blaise K. Koua^{a,*}, Paul Magloire E. Koffi^b, Prosper Gbaha^b, Siaka Touré^a

^a Laboratoire d'Energie Solaire, Université Félix Houphouët Boigny, 22 B.P. 582, Abidjan 22, Cote d'Ivoire

^b Laboratoire d'Energies nouvelles et Renouvelables, Institut National Polytechnique Félix Houphouët Boigny, B.P. 581, Yamoussoukro, Cote d'Ivoire

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ABSTRACT

In this study, achievements, potentials and perspectives for renewable energy sources in Cote d'Ivoire have been investigated. Cote d'Ivoire has abundant natural sources of renewable energy such as solar and wind power, hydraulic energy, biomass energy and biogas energy. This investigation found that solar energy, biomass energy and hydraulic energy are not being utilized sufficiently at present, but these energies could play an important role in the future of Cote d'Ivoire's renewable energy. Additionally, the potential of wind energy and biogas energy needs to be investigated. The Ivorian government's attempts to utilize renewable energy have been discussed. This paper concludes with recommendations for the development of these energy resources.

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Contents

1. Introduction	907
2. Geographic situation	909
3. Energy situation	909
4. Electricity consumption	910
5. Renewable energy sources	910
5.1. Hydropower energy	911
5.2. Biomass energy	911
5.3. Biogas energy	911
5.4. Wind energy	911
5.5. Solar energy	912
6. Policy framework for renewable energies	913
6.1. Policies, strategies and programs for renewable energy promotion	913
6.2. Regulations, incentives and legislative framework conditions	913
7. Barriers to renewable energy diffusion	913
8. Recommendations on renewable energy development	913
9. Renewable energy projects in Cote d'Ivoire	913
9.1. Projects in small hydropower	914
9.2. Projects in biomass	914
9.3. Projects in solar energy	914
9.4. Projects in wind energy	914
10. Conclusion	914
References	914

* Corresponding author. Tel.: +225 07 54 81 89.

E-mail address: kouakb@yahoo.fr (B.K. Koua).

1. Introduction

Energy resources will play an important role in the world's future. Energy is a significant factor for economic development and social prosperity of countries. There are many alternative new and renewable energy sources which can be used instead of fossil and conventional fuels. The energy resources have been split into three categories: fossil fuels, renewable resources, and nuclear resources [1]. The decision as to what types of energy source should be utilized must, in each case, be made on the basis of economic, social, environmental and safety considerations. The era of generating electric power in very large steam powered central stations seems to have ended. The increased concerns for environmental impacts of conventional fossil fuels, most importantly those related to climate change, has been the main factor driving the transition towards green energy and generation of power most favourably from renewable energy sources that are abundant and

free [2]. Governments and industries all around the world are increasingly looking for ways to reduce the greenhouse emissions from their operations with a major focus on the use and installation of sustainable renewable energy systems [3]. Renewable energy offers a range of options with which to meet the growing demand for energy, particularly in the context of the pursuit, especially in developing countries, of economic development which takes into account social and environmental issues.

Cote d'Ivoire has abundant natural sources of renewable energy such as solar and wind power, hydropower, biomass energy and biogas energy. Renewable energy resources that use domestic resources are primary and clean and are inexhaustible energy sources. These energy sources have the potential to provide energy services with zero or almost zero emissions of both air pollutants and greenhouse gases. The low population, the almost exclusive reliance on oil for energy needs, the relatively high cost of electricity, and the reasonably level of technology in Cote d'Ivoire



Fig. 1. Cote d'Ivoire's territorial divisions.

Table 1

Distribution from different sources of energy in Cote d'Ivoire.

Source	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Thermal (GW h)	3036	3085	3565	3255	3648	4128	4025	3710	3768	3667	4258
Hydropower (GW h)	1764	1800	1729	1832	1748	1433	1510	1797	1899	2131	1619

Table 2

Net electricity consumption in Cote d'Ivoire between 1960 and 2009 [5].

Year	Net electricity consumption (GW h)
1960	57.2
1965	189.5
1970	428.5
1975	790.6
1980	1518.9
1985	1725.9
1990	1938.6
1995	2070.1
2000	2892
2005	3113.2
2009	4150.7

make the renewable energy options extremely viable from a technical, social and economic point of view.

The aim of this study is to set out the current situation of renewable energy sources in Cote d'Ivoire, identifying its principal characteristics, opportunities and challenges.

2. Geographic situation

Cote d'Ivoire is a country located in West Africa. Covering an area of 322 462 km², it is the 68th largest country in the world. Cote d'Ivoire is located between 4° and 10° North latitude and 0° and 10° West longitude. Fig. 1 shows Cote d'Ivoire's territorial divisions. It is bordered by the Atlantic Ocean in the South and shares borders with Ghana in the East, Burkina Faso and Mali in the North, Guinea and Liberia in the West.

The country is influenced by two air masses: a moist equatorial air mass called monsoon and a dry tropical air mass coming along with a drying wind named Harmattan, with a saturation of 65–90%. There are four major climate zones in Cote d'Ivoire, namely an equatorial climate, a semi-damp tropical climate, a dry tropical climate and a wet tropical climate. The country knows large temperature variations between the North and the South but also throughout the year depending on the season. The temperatures throughout the year respectively range from a minimum average of 22 °C to a maximum average of 32 °C.

3. Energy situation

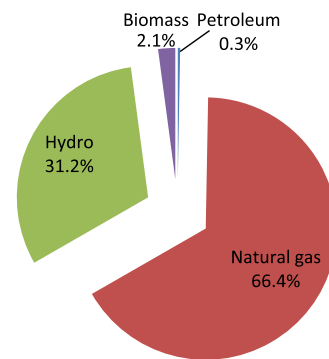
Development may occur in the form of physical infrastructural transformation, technological acquisition and human capacity building purposely undertaken to sustain modern comfort and foster the socio-economic development and globalisation of human societies. All forms of development can be achieved sustainably provided that there is adequate and sustainable interaction among energy sources, human beings and society. Interactions for constructive development of any sort require modern energy and, more specifically, electrical energy.

Cote d'Ivoire, populated of 23.2 million in 2012 with actual density of 72 inhabitants per km², is endowed with natural

Table 3

Consumption of electricity in different sectors in 2008 (%).

Tertiary	37.4
Domestic	35.6
Industry	26.7
Agriculture	0.3
Total (GW h)	3541

**Fig. 2.** Structure of electricity production in Cote d'Ivoire in 2008.**Table 4**

Electricity production by energy sources and by country in 2008 (%).

Country	Petroleum	Natural gas	Biomass	Hydraulic	Wind and solar
Bénin	99.3	0	0	3	0
Burkina Faso	64	0	13.4	22.6	0
Cameroun	25.5	7.6	0	66.9	0
Cap-vert	97.3	0	0	0	2.1
Centrafrique	0.1	0	0	99.9	0
Congo	0	16	0	84	0
Cote d'Ivoire	0.3	66.4	2.1	31.2	0
Gabon	36.4	19.7	0.5	34.4	0
Gambie	100	0	0	0	0
Ghana	46.6	0	0	53.4	0
Guinée	64.3	0	0	35.7	0
Guinée-Bissau	100	0	0	0	0
Liberia	100	0	0	0	0
Mali	46.6	0	0	53.4	0
Niger	100	0	0	0	0
Nigeria	6	66.1	0	27.9	0
Sénégal	81.2	2	2.3	13.4	0.2
Sierra Léone	100	0	0	0	0
Tchad	100	0	0	0	0
Togo	50	0	5	45	0

resources. As a developing country, Cote d'Ivoire's population continues to grow and live increasingly energy dependent lives the future of energy supply is growing. There are many sources of energy in Cote d'Ivoire currently being utilized to generate electricity. Electricity is mainly produced by thermal power plants, consuming charcoal, natural gas, fuel oil and hydropower plants in Cote d'Ivoire. Table 1 shows the distribution from different sources for last 10 years. Firewood, charcoal and agricultural waste are the

main energy source in the country. Thus, 21 million tons of wood are derived annually from agricultural clearing and specific cuts [4]. This form of energy which is essentially derived from the forest is the most widely used in Africa for cooking needs. The combustible woody (firewood and charcoal) still account for two thirds of total energy consumption. Firewood and charcoal are the combustibles most used by the households and the trend is that these combustibles will be much longer consumed with demand go hand in hand with the growth of the population [5]. However, Cote d'Ivoire possesses crude oil and gas reserves; the vast majority is located offshore. Oil production passed from 15 000 barrels per day (bbl/d) in 2002 to approximately 39 816 bbl/d in 2010 [6]. Natural gas production was 64.109 billion cubic feet in 2010 [6].

4. Electricity consumption

The rapid economic development has created substantial increase in energy consumption. Electricity consumption in Cote d'Ivoire has been increasing almost exponentially since 1960, and according to many energy experts, it will keep on increasing in the following decades due to high economic growth and increasing population. Per capita consumption (kilowatt hour) more than doubled. Table 2 shows the net electricity consumption in Cote d'Ivoire between 1960 and 2009 [7]. Table 3 shows the consumption of electricity in various sectors for the year 2008 [8]. One can see that, the tertiary sector consumes the maximum electricity followed by the domestic sector (light, refrigeration, cooking, water heating...).

Despite the rising energy demand in Cote d'Ivoire, the electrification rate is still low. To meet the rising demand for electricity, Cote d'Ivoire is heavily reliant on fossil fuels rather than cleaner sources of electricity such as hydropower, solar energy. Fig. 2 illustrates the participation of different sources in the internal supply of electricity in Cote d'Ivoire. It can be seen that Cote d'Ivoire has an electricity generation matrix based mainly on thermal source and hydropower generation.

It is apparent that the nominal potential of renewable energy in Africa is great but the sustainable political will and enthusiasm to enact the regulatory framework for exploitation through modern techniques is low [9]. This disparity is explained in more detail in Table 4 [10], which expresses the electricity production by energy sources. Therefore, to correct this disparity, approximately 5, 15 and 20% of electricity must be produced from renewable energy sources (excepted hydropower) in 2015, 2020 and 2030, respectively in order to meet the vision of Cote d'Ivoire's government [11]. Also, in 2012, the Cote d'Ivoire committed to promoting

renewable energies by setting up a project to create pilot firms, to produce green energy—primarily hydropower, biomass energy, solar and wind power— to mitigate the increase in fossil fuel use.

5. Renewable energy sources

Renewable energy is, by definition, sustainable and clean and in addition offers the opportunity to tackle the increasing depletion of fossil resources and the associated environmental impacts [12]. The distribution of main renewable energy sources in Cote d'Ivoire is dominated by hydraulic energy and biomass energy, but environmental and scarcities of supply concerns have led to a decline in biomass energy use. As a result, the composition of renewable energy supply has changed wind energy and solar energy are beginning to claim market share. As a contributor of air pollution and deforestation, the share of biomass energy share is expected to decrease with the expansion of other renewable

Table 5

Status of the hydropower development in Cote d'Ivoire.

Hydraulic power plants	Installed power (MW)	Annual producible (GW h)
Ayamé 1	20	80
Ayamé 2	30	130
Kossou	174	450
Taabo	210	800
Buyo	165	880
Gah	5	20

Table 6

Large hydroelectric potential.

River	Site	Available capacity (MW)
Cavaly	Tahibli	20
Bandama	Tiassalé	51
Bandama	Singrobo	67
Sassandra	Gao	74
Bandama	Kokumbo	78
Comoé	Malamalasso	90
Bandama	Brou Atakro	90
Sassandra	Daboitier	91
Comoé	N'Dieliesso	100
Sassandra	Gribo popoli	112
Comoé	Aboisso	150
Sassandra	Bouloubré	156
Cavaly	Tiboto	220
Sassandra	Soubré	275
Sassandra	Louga	280
Total		1854

Table 7

Small hydroelectric potential.

River	Site	Available capacity (MW)
Agneby	Agboville	0.169
Lobo	Daloa	0.172
Agneby	Agboville	2.016
Drou	Man	2.5
Pale	Boundiali	3.51
Comoé	Tehini	4
Bandama	Korhogo	4
Bia	Aboisso	6.4
Bandama	Ferkessedougou	7.32
Marahoué	Mankono	8
Total		37.918

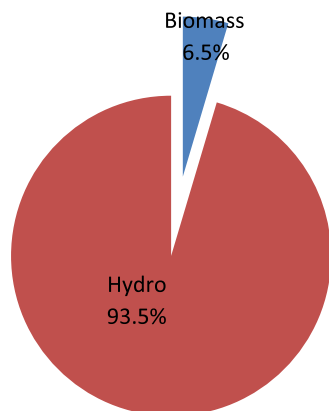


Fig. 3. Structure of electricity production from renewable energy in Cote d'Ivoire in 2008.

energy sources. Fig. 3 shows the structure of electricity production from renewable energy sources in 2008 [8].

5.1. Hydropower energy

The benefit of natural resources which becomes sources of energy production is a strategic advantage for any country. The advantages include a reduction of dependence on external supplies and consequent increased stability in terms of the supply of a service which is vital to social and economic development [13].

Hydropower generation captures and converts the kinetic energy of flowing water into electrical energy. It is the cleanest renewable energy source with a further two advantages: the low cost of supply compared to other sources (coal, oil, uranium and natural gas for example) and the fact that the operation of hydropower plants does not provoke major emission of greenhouse gases, so that it compares favorably with the alternatives. Cote d'Ivoire is rich in hydropower energy potential with a water surface area of 1.38% of the total country area. Maximum exploitable hydropower resources in Cote d'Ivoire are approximately 2458 MW, which are currently economically exploitable. To date, only 25% of the total hydroelectric power potential (around 604 MW) is operational as shown in Table 5 [14]. The national development plan aims to increase this to 100%. The construction plans of hydroelectric power plants predict to install 275 MW at Soubré, a city located in the West central in the short term (2011–2018), and 474.5 MW in country in the long term (2020–2030). A large hydropower plant (Table 6 [14]) requires for construction a high investment cost and technology which is not suitable as a decentralized supply system in a rural area with a load factor relatively low. Micro or mini hydropower technologies are appropriate for small rural communities which are located close to small rivers. Table 7 indicates that there are several small or rivers branch distributed nearly throughout the country [15].

5.2. Biomass energy

Biomass is organic material that has stored sunlight in the form of chemical energy. All biomass is produced by green plants converting sunlight into plant material through photosynthesis [16]. Biomass can be used to meet a variety of energy needs, including generating electricity, heating homes, fueling vehicles and providing process heat for industrial facilities. Biomass energy is the most common energy source in Cote d'Ivoire. Up to 60% of the overall energy requirements are covered by this energy source, including [14]:

- Fuel wood and charcoal for households, small restaurants, bakeries, arts and crafts centers (smithies, jewelry-making shops, potteries ...);
- Agricultural and forest residues for the production of steam and/or electricity in some agro-business companies (oil works, sugar refineries ...) and sawmills.

Resources from agro-industrial residues, crops and plantations are estimated at 4.3 million tons of oil equivalent per year (toe/year) [14].

They represent a key energy source and the most directly useable renewable energy potential. Data regarding the total quantity of exploitable biomass in Cote d'Ivoire is not fully committed to renewable energy development but instead has applied traditional techniques of biomass energy exploitation. Table 8 presents an estimation of the available biomass potential [14]. In Cote d'Ivoire, the valuation of the plant and agro-industrial residues is mainly due to sawmills and food industries which use

Table 8
Biomass potentiel.

Geographic area	Form of residu	Value (toe)
North	Bagasse	120000
	Sugar cane molasses	30000
	Cotton seed shell	10475
Center and South	Cobs, palm fiber and shell	100000
	Shell, coffee hull	32.15
General use	Cocoa beans	74000
	Cocoa cobs and shells	25000
	Rice husk	10000
	Urban waste	104.41
District of Abidjan	Urban waste	> 1000 000

them for their own heat and electricity needs. There are several auto-producers of electricity using agro-industrial residues [7]:

- SODESUCRE: 4 sugar industries burning bagasse (50 MW)
- PALMINDUSTRIE: oil mills burning fibers and shells of palm (25 MW)
- TRITURAF: oil mill burning shells of cottonseed (2 MW)
- THANRY: sawmill burning solid wastes (1.5 MW)
- SICOR: grated coconut plant burning wads and shells (1 MW)

5.3. Biogas energy

Biogas is a mixture of gases generated from anaerobic digestion of the organic fraction of solid waste. It is a very clean source of energy especially for cooking. The main component and useful gas in biogas is methane, which is a highly combustible substance with high- quality calorific value. Biogas production is significant in controlling and collecting organic waste and fertilizer production for agriculture [17].

In Cote d'Ivoire, biogas sources are abundantly available but development is confronted with several challenges. The foremost restraining factors of biogas programs are the high capital investment expenditure, minimal practical demonstration, technical problems and cultural issues [18]. Thus, biogas technology is not yet developed in Cote d'Ivoire. Units that have been installed for the biogas production are usually experimental. There are:

- Three industrial biogas digesters with a capacity of 2100 m³ have been installed which one at Toumodi for Ivorian Company of Tropical Technology and two at Ferkessedougou for Industrial Complex Exploitation of Cattle.
- Five biogas plants with a capacity of about 15 m³ each have been built for primary schools with canteens in northern of Cote d'Ivoire benefiting nearly one thousand students.

5.4. Wind energy

Wind energy has been utilized by man for centuries, initially to provide mechanical energy and now to provide electricity generation. It is available virtually everywhere in the world. The energy from continuously blowing wind can be captured using wind turbines that convert kinetic energy from wind into mechanical energy and then into electrical energy [19].

Feasible data about the wind potential in Cote d'Ivoire is not available. There are only some basic measurements of wind velocities which certainly are not sufficient accurate for knowing the potential at different heights but at least can give an orientation of the wind velocities distribution across the country. Wind velocities have been tapped in specific locations. In San Pedro on

the shoreline and in Korhogo in the north the highest wind velocities have been measured (6 m/s at 10 m height). Other average velocities have been tapped in the Center in Bouake and in Tabou on the western shoreline with averages of 4 m/s [14]. Average wind velocity in Cote d'Ivoire is inferior to 4 m/s.

The development of wind energy in any part of the world needs to be influenced by strong government policy. At present there is no strong supportive mechanism for the promotion of wind energy development in Cote d'Ivoire but micro-scale consumption of wind energy has been utilized in several villages. Wind energy systems installed are widely used for water pumping.

5.5. Solar energy

Solar power is a form of energy generated from the effects of solar radiation created from a positive enthalpy change in the solar body, which is propagated in a waveform through the phenomenon of solar thermal radiation. Solar energy is the most abundant energy resource on the planet and is available for direct (solar radiation) and indirect (wind) use.

Solar energy is abundant in Cote d'Ivoire, where the average solar radiation ranges between 4 kW h/m² per day (at South) and 6 kW h/m² per day (at North) with a daily sunshine time of 6 h.

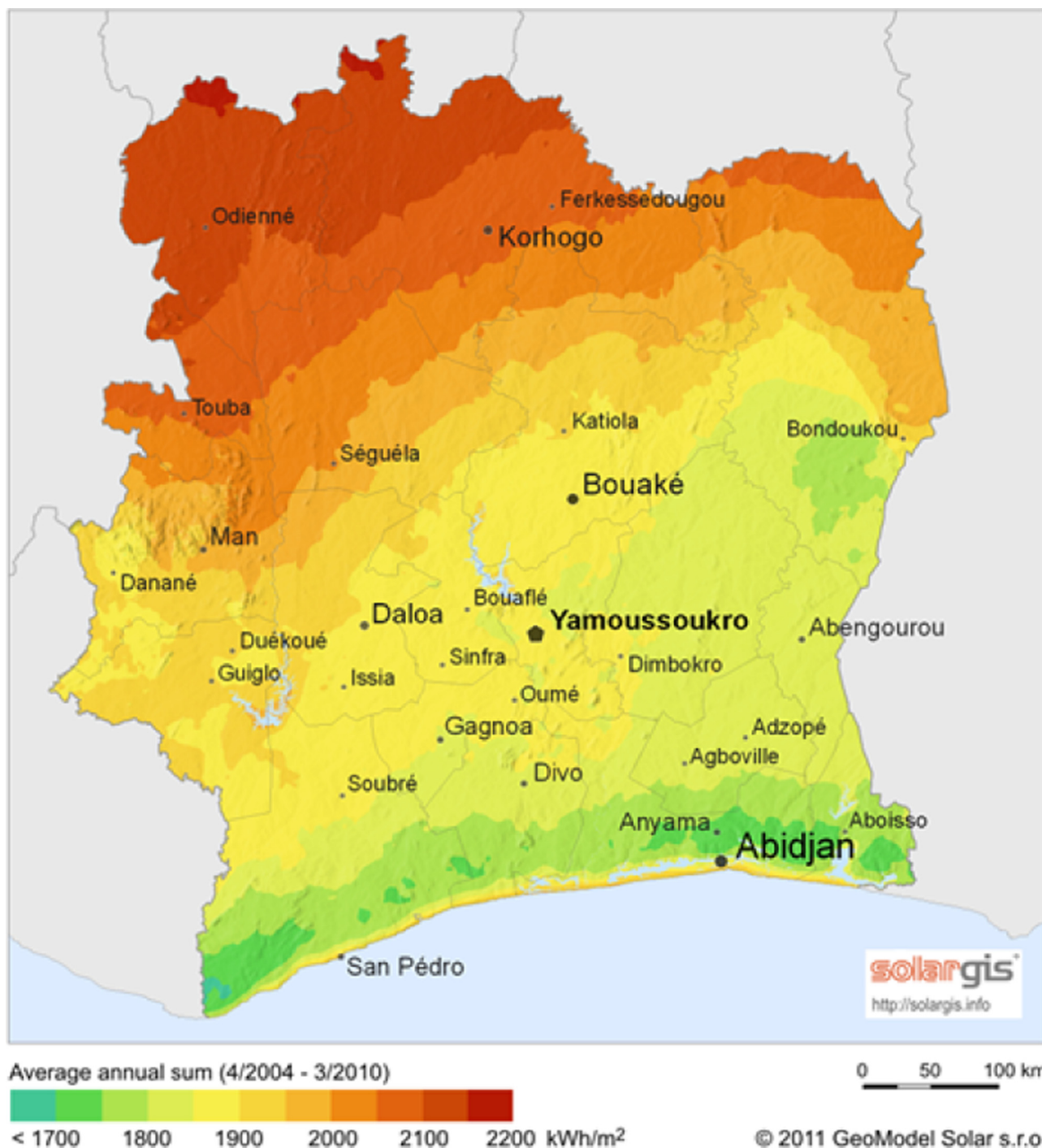


Fig. 4. Global horizontal irradiation in Cote d'Ivoire.

Fig. 4 illustrates the variation of global horizontal irradiation in Cote d'Ivoire, indicating that the highest rates are observed in the Northeast region and the lowest rates in the Southeast region.

However, solar energy has not been adequately exploited compared to its naturally endowed potential in Cote d'Ivoire. Solar energy in Cote d'Ivoire is effectively adopted for heating, lighting and drying using two routes: the thermal route mainly for drying and heating, and for the generation of electricity, in particular via photovoltaic panels for various uses as lighting, pumping and communication. All the photovoltaic systems in Cote d'Ivoire are not connected to the electricity grid. The solar energy is very effective in electrifying the remote villages which may otherwise involve huge investment in laying power transmission lines. As part of the remote villages' electrification program, solar energy-powered, electrical lighting systems were introduced. Projects have thus been sanctioned for extending lighting facility to un-electrified villages using micro photovoltaic solar plants. These systems are also installed and managed by some households. Several telecommunication facilities have also been equipped with photovoltaic solar energy systems for stand-alone energy supply. Solar dryers and solar water heating systems are installed and managed by some households or small communities. Solar dryers are used mostly by cooperatives of coffee and cocoa. Solar ovens and solar cookers have not yet started being popularized.

Recently, some private operators have started activities basically oriented towards the import sale and installation of solar equipment.

6. Policy framework for renewable energies

6.1. Policies, strategies and programs for renewable energy promotion

The development of renewable energy is hindered by a lack of comprehensive planning as Côte d'Ivoire does not have a clearly defined energy policy with substantial financial means to promote renewable energy. On the institutional level, the management of renewable energy is incumbent on the Energy Directorate and is ensured through the Sub-Directorate of Energy Control and Renewable Energies. Several operators and institutions (ministries, research institutes and centers, etc.), however, are active in this sector without genuine coordination. In 2009, the decision to establish a Renewable Energy Directorate within the Ministry of Petroleum and Energy has set a distinctive hallmark in the official renewable energy development policy.

Today, a new code of electricity is being adopted. It should allow disposing a regulatory, legal and fiscal framework clean to the renewable energies. Thus, the operators of renewable energy production could benefit from tax and customs advantages in the form of exemptions and reduction of taxes, to enable them to exploit the enormous potential of the country in renewable energy resources.

6.2. Regulations, incentives and legislative framework conditions

As already mentioned, there is a massive lack in legal and fiscal framework conditions for the implementation and promotion of renewable energy. Up to now, there are no specific regulations, incentives or legislative framework conditions available. The new regulations currently being drafted at the Ministry of Petroleum and Energy will, however, provide the necessary environment to develop the renewable energy sub-sector in Côte d'Ivoire.

Several private enterprises are getting involved in rural electrification after securing the approval of SOPIE, the principal contractor for the provision of electrical facilities. In order to obtain this approval, all enterprises applying have to give evidence of their financial and technical capacities. The National Authority

(AN-MDP) is responsible for the Clean Development Mechanism (MDP) implementation in Cote d'Ivoire. The AN-MDP focal point is housed at the National Environmental Agency (ANDE). The national work plan on the MDP has been validated since May 2003. Several projects (development of household wastes, sustainable forest management etc.) are currently being evaluated in order to classify them as projects liable to be funded within the opportunities provided by the MDP.

7. Barriers to renewable energy diffusion

The institutional barriers such as lack of financial institutions to support renewable energy, lack of a sound legal and regulatory framework and absence of adequate financial incentives have been limiting the diffusion of renewable energy. Furthermore, the limited access to advanced technologies in developing countries is one factor limiting the use of renewable energy. Even when there is access, the cost of procuring such technologies is very high. Lack of detailed renewable energy resource assessments and databanks pertaining to Cote d'Ivoire is also a limiting factor for the development of renewable energy. On top this, there are socio-cultural barriers such as the hesitation to opt for renewable sources of energy in households for fear of reliable service, lack of awareness about the benefits of such renewable energy and lack of political will to promote renewable energy.

8. Recommendations on renewable energy development

Authors' recommendations on renewable energy development can be summarized as follows:

- More studies need to investigate wind and biogas energies.
- Financial support for studies that investigate renewable energy in Cote d'Ivoire and its applications is required.
- Projects in renewable energy are encouraged and sponsored. A particular emphasis is placed on research and graduate programs in renewable energy science that will serve as workforce catalysts for promoting increased use of renewable energies in Cote d'Ivoire and encourage the gradual move toward a more conscious and sustainable use of these energy sources.
- Adequate cross sector and international collaboration is also considered necessary to ensure the proper application of renewable energy.
- For successful development of renewable energy systems, foreign assistance is highly inevitable policy advocating for cooperation, a cross section between the energy sector on one hand and other important sectors in possession of renewable energy resources such as agriculture, environment and forestry needs to be developed.
- Connection to the electric grid interconnected or mini electric grid: Private developers can settle down as the independent producers of electricity through a convention signed with the government. Their production power plants of electricity from renewable energy may be connected to the interconnected grid.
- Individual equipments: Individual equipments based on renewable energy can be developed by promoters among populations through innovative financing mechanisms with the guarantees, the coordination and possible reductions of fiscal and customs taxes granted by the government.

9. Renewable energy projects in Cote d'Ivoire

Renewable energy projects in Côte d'Ivoire are led by the private sector and the public sector. The projects are from various

sources: hydraulic, biomass, solar, wind. These projects are extracts from the acts of the national seminar on energy [11].

9.1. Projects in small hydropower

- Fitting out hydropower of Drou of capacity 1.5 MW
- Micro hydropower plant of 300 kW on River Agnéby
- Fitting out hydropower of Aboisso-Bia of capacity 5 MW

9.2. Projects in biomass

- Vulgarization of the use of fireplaces improved in rural area
- Electricity production from the solid wastes of the district of Abidjan by the SITRADE group
- Electricity production using the discharge biogas of Akouédo by the EOULEE group

9.3. Projects in solar energy

- Electrification of rural localities by solar photovoltaic system
- Electrification of 200 health centers by solar photovoltaic system in rural zones
- Installation of solar pumps in 580 drilling
- Diffusion of 112 500 sun lamps in isolated localities of the electric grid
- Irrigation of 100 ha of vegetable crops by solar pumping

9.4. Projects in wind energy

- Pilot project of 100 kW of wind energy. This project is subject to a prior study to the wind potential.

Apart from projects already formulated by different promoters, we can also evoke the potential projects on the basis of the available renewable energy resources on Ivorian territory.

- Projects of electricity production from biomass (agro-industrial wastes of coffee, cocoa, Palm, sugar cane, cashew nut, corn, pineapple, rubber wood, wood sawdust...)
- Project of energetic valorization of household and industrial garbage
- Projects of electricity production from selected sites of micro hydraulic
- Projects of electricity production from identified sites in solar

10. Conclusion

Renewable energy resources appear to be the one of the most efficient and effective solutions for clear and sustainable energy

development in Cote d'Ivoire. Renewable energy supply in Cote d'Ivoire is dominated by hydropower and biomass energy. There is also significant potential for wind power development. Cote d'Ivoire has great renewable energy potential and is keen to reduce its dependence on fossil fuels by increasing its use of renewable energy.

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